

Evidence for Temporally-Extended, High-Energy Emission from Gamma Ray Burst 990104

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ABSTRACT

It is well known that high-energy emission (MeV-GeV) has been observed in several gamma ray bursts, and temporally-extended emission from lower-energy gamma rays through radio wavelengths is well established. Observations of extended, high-energy emission are, however, scarce. Here we present evidence for a gamma ray burst emission that is both high-energy and extended, coincident with lower energy emission. For the very bright and long burst, GRB 990104, we show light curves and spectra that confirm emission above 50 MeV, approximately 152 seconds after the BATSE trigger and initial burst emission. Between the initial output and the main peak, seen at both low and high energy, there was a period of ~ 100 s during which the burst was relatively quiet. This burst was found as part of an ongoing search for high-energy emission in gamma ray bursts.

Subject headings: gamma rays: bursts—gamma rays: observations

1. Introduction

Over a period of nine years, the Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory (CGRO) detected ~ 2700 gamma ray bursts (Paciesas et al. 2001) at a rate of approximately one per day (Meegan et al. 1992). While the Current BATSE Burst Catalog contains nearly three thousand bursts, only a few are known for MeV-GeV emission (e.g. Schneid et al. 1992, 1995; Hurley et al. 1994; Kwok et al. 1994; Schaefer et al. 1994; Share et al. 1994; Sommer et al. 1994; Catelli, Dingus, & Schneid 1998; Briggs et al. 1999; Gonzalés et al. 2001). One of these, GRB 940217, had very high-energy, temporally-extended emission, including one ~ 20 GeV photon, which arrived

approximately 75 minutes after low-energy emission had ended (Hurley et al. 1994). The prevalence of such extended emission is an open question to be addressed in the GLAST era. In this context, we have undertaken a search for high-energy emission from gamma ray bursts, with a particular focus on extended emission. To this end, we used data from the EGRET instrument on board the Compton Gamma Ray Observatory.

In the course of this search, we found extended, high-energy emission from GRB 990104. We present time profiles and high-energy spectra of this burst, which is noteworthy for several reasons:

- with a 50–300 keV peak flux of 86.53 ± 0.93 photons $\text{cm}^{-2} \text{s}^{-1}$ on the 64ms time scale, it ranks fifth in brightness among BATSE catalog bursts;
- its 50–300 keV fluence of $(1.67 \pm 0.11) \times 10^{-4}$ ergs cm^{-2} is greater than that of all but one burst in the BATSE catalog;
- its duration is greater than that of 96% of catalog bursts for which duration is reported; and,
- most significantly, the light curves, count rates, and spectra indicate that there is a relatively quiet period of ~ 100 seconds between the first emission and the most intense outburst, during which the measured emission extends past 50 MeV.

While similar characteristics have been detected in other bursts (e.g. Tkachenko et al. 1995; Connors and Hueter 1998; Giblin et al. 1999), GRB 990104 is rare in that we see all of these behaviors in one burst. In a later paper, we will present results of a broader survey for high-energy, extended emission from gamma ray bursts.

2. Time Profiles

2.1. Burst Position

During the burst, the earth occulted the telescope, and the EGRET spark chamber was powered off. However, two other components of the EGRET instrument, the Total Absorption Shower Counter (TASC) NaI calorimeter, and the anticoincidence scintillator dome, are omnidirectional, making burst detection possible. The TASC and anticoincidence dome yield no positional information, so the direction for the burst was taken from the BATSE catalog. This placed the burst at $l^I = 224.93^\circ$, $b^I = 24.51^\circ$, which is 155° from normal in spacecraft coordinates; therefore, the burst came from “underneath” the telescope. We note that another CGRO instrument, COMPTEL, has no published listing of this burst.

2.2. TASC Operation

The TASC operated in two modes, with the normal mode accumulating spectra continuously over 32.768 s intervals. When a burst trigger was received from BATSE, the TASC transitioned to burst mode, during which time spectra were taken for 1, 2, 4 and 16 s consecutive intervals. These burst mode intervals, while useful for bursts in which emission came soon after a trigger, did not aid with spectrum measurements for longer bursts. However, normal mode accumulation would resume when a 23 s burst mode accumulation was over, providing for the production of continuous, 32.768 s spectra

2.3. Light Curves

Continuous data of another sort was provided by EGRET’s anticoincidence dome. The primary task of the anticoincidence dome was to provide a means of vetoing signals from cosmic rays interacting with the telescope. It also was sensitive to large fluxes of low energy gamma rays, primarily around 100 keV, allowing for the measurement of light curves with 0.256 s resolution. In Figure 1, this anticoincidence count rate is shown between a BATSE 25–60 keV light curve (above), and TASC rate counts (below). BATSE, with a resolution of 0.064 s, clearly has the most detailed curve, while the TASC rates have coarse 2.048 s time bins. However, the TASC discriminators, with energy thresholds of about 1, 2.5, 7, and 20 MeV, provide information on the time profile in a higher energy range. Of these, emission is visible in the >1 , >2.5 , and >7 MeV rates. All three detector systems show a spiky rise at or near the BATSE trigger time, T , of 16:02:33.72 UT (57753.72 s), followed by a period of approximately 100 s of output that is mostly consistent with background. Then ~ 152 seconds after the trigger ($T+152$ s), the main emission begins.

2.4. Burst Background

Summing spectral counts provides another means of examining the activity of the burst. Summing the raw TASC counts in a 1–200 MeV spectrum and dividing by the livetime gives an average count rate for that time interval. Figure 2 is a plot of raw count rates for normal mode (32.768 s) spectra, covering a 720 s span. There is a clear rise in rates at the time of the main emission, on top of a slow, steady decay in the background rate. To define a background sample, we excluded the burst intervals in the span of $T-5$ – $T+192$ s, allowed for a one accumulation interval gap before and after the burst, and selected the next seven intervals both before and after the burst. We fit a line to the background rates in these intervals ($T-267$ – $T-37$ s and $T+224$ – $T+454$ s), and derived

estimated background rates in between. Because the overall decay in background rates was smooth, the burst-time derived background rates were insensitive to the choice of pre and post burst background intervals. Figure 3 shows the background subtracted normal mode count rates. Comparison of Figures 1 and 3 shows a strong correlation between the time profiles of light curves and spectral counts.

We note that there may be a hint in the anticoincidence rates and lowest threshold TASC counters that there also is emission at $T+84$ s, but this not visible in the spectral rates in Figure 3, or in the BATSE light curve, and the weak signal disallowed a spectrum measurement.

3. High Energy Spectra

Spectrum measurements require TASC detector spectra to be converted to photon spectra through the use of a direction and energy dependent response matrix. These factors are computed with the CGRO mass model and EGS4 Monte Carlo code (Nelson, Hirayama, & Rogers 1985), which accounts for the detector geometry and intervening spacecraft material.

The background-subtracted rates in Fig. 3 are a guide as to whether a given interval can yield a spectrum measurement. Figures 4a and 4b show strong spectra during the two normal mode intervals corresponding to $T+126 - T+159$ s and $T+159 - T+192$ s, where spectral count rates are highest. For the first of these, a single power law of the form $F(E) = \alpha(E/\text{MeV})^{-\beta}$ is fit over 1–20 MeV, with a resulting spectral index of 2.66 ± 0.17 and normalization constant of 0.64 ± 0.12 photons $\text{cm}^{-2} \text{s}^{-1} \text{MeV}^{-1}$. Light curves indicate that the second interval covers more of the emission, which allows a single power-law fit over 1–100 MeV. This gives an index of 2.52 ± 0.03 and normalization constant of 2.68 ± 0.12

photons $\text{cm}^{-2} \text{s}^{-1} \text{MeV}^{-1}$. For comparison, when this second spectrum is fit over the same 1–20 MeV range as the first, the result is a constant of 2.64 ± 0.12 photons $\text{cm}^{-2} \text{s}^{-1} \text{MeV}^{-1}$ an index of 2.50 ± 0.04 , consistent with the 1–100 MeV fit. Though these normal mode spectra were strong, none of the four burst mode intervals had enough signal for spectrum measurements.

The spectral characteristics of this burst are toward the high end of the $\beta=1.7$ to 3.7 distribution reported by Catelli, Dingus, & Schneid (1998) for the sixteen bursts they considered, while slightly harder than the TASC-only, $\beta=2.71 \pm 0.08$, of the much studied GRB 990123 (Briggs et al. 1999).

4. Summary

We have observed unusual, high-energy, temporally-extended emission from a very bright gamma ray burst. Light curves over a wide 25 keV – 7 MeV energy range are consistent in showing that the main emission begins ~ 152 seconds after the BATSE trigger. This is confirmed by spectral count rates and two strong spectra, which cover T+126 – T+192 s. The burst is somewhat softer than most of the others that have previously been detected in the TASC, with spectral indices 2.66 ± 0.17 and 2.52 ± 0.03 . The first spectrum is strong enough for a fit from 1–20 MeV, and the second up through 100 MeV, with no high-energy cutoff observed.

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¹The Current BATSE Burst Catalog is available at:
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Fig. 1.— Light curves from BATSE, EGRET’s anticoincidence dome, and EGRET’s TASC NaI calorimeter. Plots on the right are expanded regions of the full light curves on the left. The vertical dashed line indicates the time of the BATSE trigger. The dotted lines mark the beginning and end of two normal mode (32.768 s) spectra shown in Figure 4.

Fig. 2.— TASC raw count rates for normal mode (32.768 s) intervals. A dotted line is drawn through the times when the TASC was in burst mode, and normal mode spectra were not being integrated.

Fig. 3.— TASC background subtracted count rates for normal mode (32.768) intervals. A dotted line is drawn through the time period for which the TASC was in burst mode, and normal mode spectra were not being integrated.

Fig. 4.— TASC photon spectra for two normal mode (32.768 s) intervals. Fig. 4a shows a single power law fit over 1–20 MeV as a line passing through the data points. This is for the normal mode (32.768) interval covering T+126 – T+159 s (57880 – 57913 s UT). The dotted line is an extrapolation of that fit to higher energies. The spectral index was measured to be 2.66 ± 0.17 , with a normalization constant of 0.64 ± 0.12 photons $\text{cm}^{-2} \text{s}^{-1}$. Fig. 4b shows a single power law fit over 1–100 MeV, covering the normal mode interval T+159 – T+192 s (57913 – 57946 s UT). The spectral index was measured to be 2.52 ± 0.03 , with a normalization constant of 2.68 ± 0.12 photons $\text{cm}^{-2} \text{s}^{-1}$.

Count Rate (kHz)









